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Nearshore Circulation

F. P. SHEPARD and D. L. INMAN

(Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950. This paper appears as Chapter 5 in the Proceedings.)

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Submarine Geology Report No. 14
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Roger Revelle

Roger Revelle, Director

CHAPTER 5

NEARSHORE CIRCULATION*

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University of California
La Jolla, California

INTRODUCTION

Studies of nearshore circulation were initiated at Scripps Institution during World War II. A method of estimating the velocity of longshore currents from known wave conditions on straight beaches with parallel contours was devised by Munk and Traylor (1945) and later revised by Putnam, Munk and Traylor (1949). Their methods were based on energy and momentum considerations which were applied to the following two types of observations: (1) field observations of longshore currents along the straight beach at Oceanside, California made by Munk and Traylor (1945), and (2) laboratory measurements conducted at the Department of Engineering, University of California.

In 1945 a program of field observations was initiated to study the nearshore currents in relation to a variety of coastal types and submarine configurations. Operations extending over a period of one year involved measurement of currents inside the breakers at 63 stations from the United States -- Mexican boundary to Newport, California (Shepard, 1950) (Fig. 1). The observations were repeated approximately every 12 days. Subsequently the shallow waters adjacent to individual beaches representative of various types of environment have been studied intensively. This work has included a beach with adjacent submerged ridge and canyon topography (Shepard and Inman, 1950), two straight beaches with parallel bottom contours, and one beach at the head of a crescentic bay. In addition the effects of jetties, piers, and points have been investigated. During this work currents inside and outside the breaker zone were investigated. Most of the observations were made in southern California, but studies along many other coasts of the United States and in the Hawaiian Islands indicate that the results have a general application.

All devices used in these investigations were of a free drifting type, the velocity being determined by the distance of travel in a given period of time. Currents outside of the surf zone were measured by surface floats, dye, and triplanes (current crosses) submerged at a variety of depths. Locations were obtained by multiple sextant angles from accompanying boats. Inside the breaker line bottom currents were measured by volley balls given slight negative buoyancy. Surface currents were observed by free floating kelp and dye. Details of the methods are given by Shepard and Inman (1950). Wave recordings were obtained simultaneously with many of the measurements. Angles of wave approach were determined in part by the transit-sighting bar method devised by Forrest (1950).

TERMINOLOGY AND GENERAL PRINCIPLES OF CIRCULATION

Observations of nearshore circulation show that there are certain basic principles which apply to most environments, including in varying degree straight beaches with parallel offshore contours and beaches adjoined by irregular submarine topography. There appear to be at least two interrelated current systems (Fig. 2):

1. The coastal currents which flow roughly parallel to the shore, and constitute a relatively uniform drift in the deeper water adjacent to the surf zone. These currents may be tidal currents, transient wind-driven currents, or currents associated with the distribution of mass in local waters.

*Contribution from the Scripps Institution of Oceanography, New Series No. 532. This work represents in part research carried out for the Beach Erosion Board and the Office of Naval Research under contracts with the University of California.

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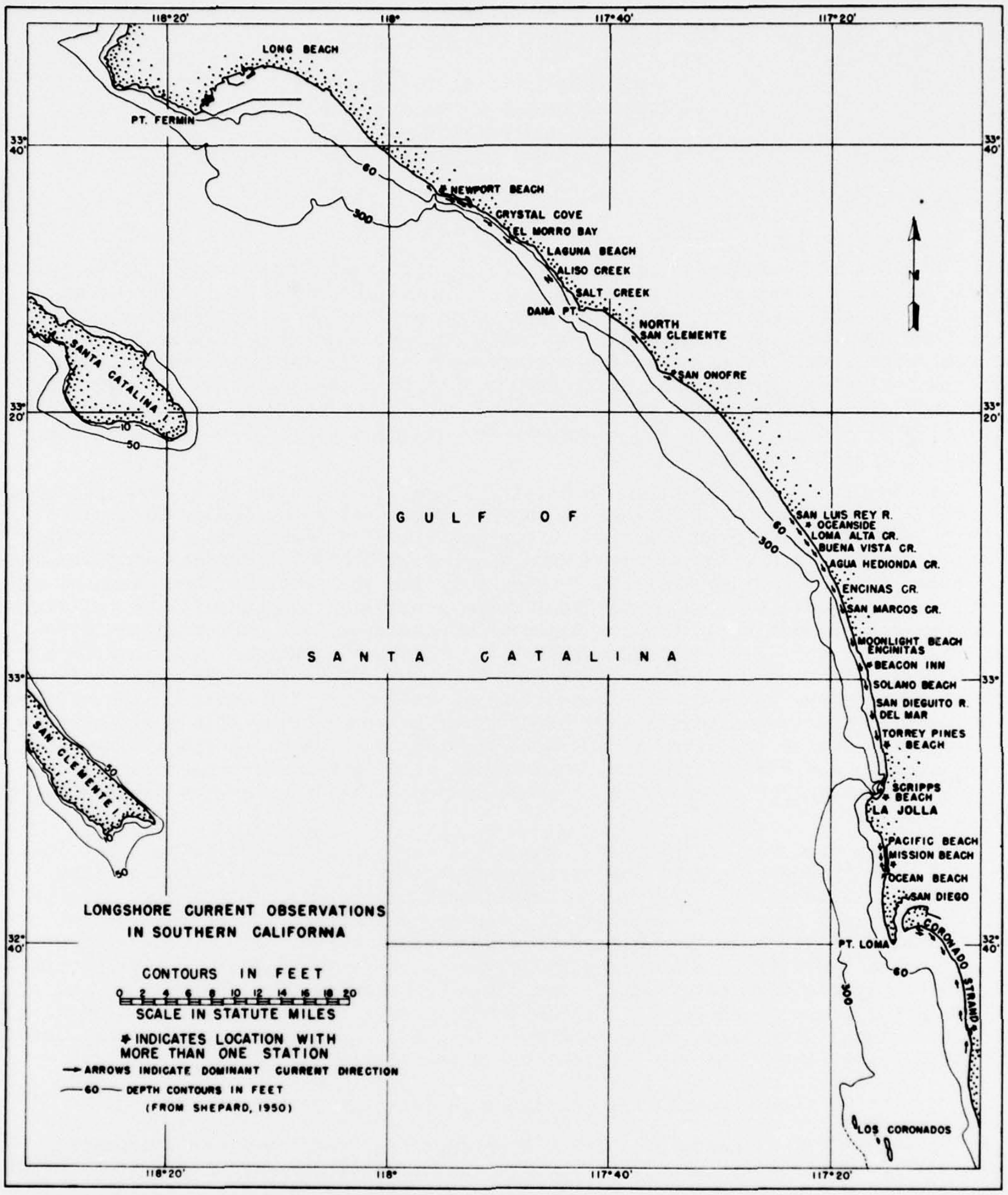

Fig. 1
Showing areas where nearshore current measurements have been made in southern Calif.

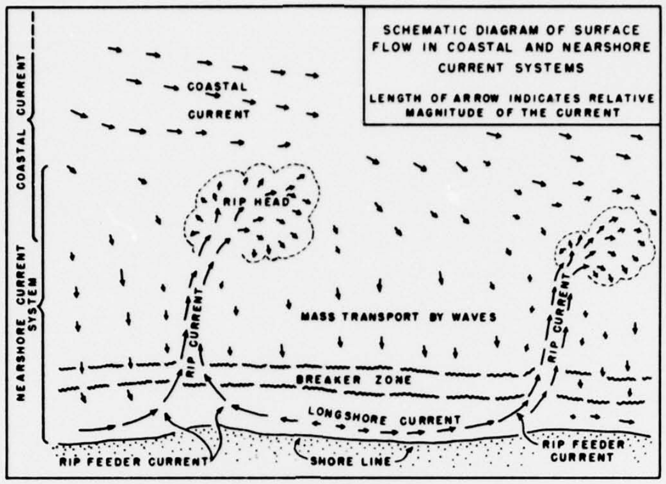

Fig. 2

2. A nearshore system which may be superimposed on the inner portion of the coastal current or in the absence of a coastal current may exist independently. The nearshore system is associated with wave action in and near the breaker zone and consists of: (a) shoreward mass transport of water due to wave motion, which carries water through the breaker zone in the direction of wave propagation, (b) movement of this water parallel to the coast as longshore currents, (c) seaward return flows, such as flow along concentrated lanes known as rip currents, and (d) longshore movement of the expanding head of the rip current.

Since the rip currents have relatively high offshore velocities, the shoreward movement is restricted to wide lanes in between rip currents. As a result, the circulation pattern takes the form of an eddy or cell with a vertical axis (Fig. 2). The positions of shoreward motion and seaward return are much dependent on the submarine topography, the configuration of the shoreline, and the height and period of the waves. Periodicity or fluctuation of current velocity and direction is a characteristic of flow in the nearshore system (Shepard and Inman, 1950). This variability is primarily due to the grouping of high waves followed by low waves, a phenomenon which gives rise to surf beat (Munk, 1949b).

The direction of longshore current is primarily dependent on two factors: (1) the direction of wave propagation, and (2) the rise in water level due to the shoreward mass transport of the waves, which is greatest in the zones of highest breakers along a beach (wave convergence zones). The longshore currents commonly flow away from these zones of highest waves.

There may be processes other than rip currents by which water may be returned seaward (Munk, 1949a). Our observations indicate the importance of a net seaward drift along the bottom inside the breaker zone and a net shoreward movement at the surface. Comparisons of the offshore and onshore components of surface and bottom currents in the surf zone are given in Table I. This table shows that there is a definite tendency for bottom longshore currents to have a small offshore component. The lack of a pronounced onshore component for the surface currents is probably due to the method of observation (see footnote to Table I on following page).

To date we have not found any indication that these differential net movements between top and bottom extend any distance outside of the breaker zone, but rather that the current moves shoreward from top to bottom in one area and seaward from top to bottom in another outside of the breaker zone.

TABLE 1

Comparison of the offshore and onshore tendencies between surface and bottom currents in the surf zone. Based on all observations, irrespective of magnitude.

Location	Surface Currents[1]			Bottom Currents[2]		
	No. of Obs.	% Offshore	% Onshore	No. of Obs.	% Offshore	% Onshore
Torrey Pines Beach	139	54.7	45.3	512	81.4	18.6
Pacific Beach	162	47.5	52.5	220	81.8	18.2
Mission Beach	224	50.0	50.0	383	76.3	23.7
Total No. of Obs.	525			1115		
Average %		50.5	49.5		79.7	20.3

[1]Surface currents were measured by free floating kelp and dye and thus represent measurements of a relatively thick surface layer and not the surface itself which is known to have a greater onshore tendency (Shepard and Inman, 1950, p. 200).

[2]Bottom currents were measured with volley balls given slight negative buoyancy.

STRAIGHT BEACHES WITH PARALLEL CONTOURS

Most beaches have some curvature and the adjacent bottom topography is usually somewhat irregular. However, there are a sufficient number of beaches which are essentially straight with parallel bottom contours to warrant consideration. This type of beach is ideal for theoretical treatment and was therefore chosen for the investigations of longshore currents by Putnam, Munk and Traylor (1949). Their momentum approach has been widely used. It relates the velocity V, of the longshore currents to the wave height H, period T, angle of approach α, and slope i of the beach, according to the equation:

$$V = \frac{a}{2}\left[\sqrt{1 + \frac{4C \sin\alpha}{a}} - 1\right] \tag{1}$$

where $a = (2.61\ i\ H \cos\alpha) \,/\, (kT)$

and, $C = \sqrt{2.28\ g\ H}$ is the wave velocity, k is the beach friction coefficient (hydraulic roughness), and g is the acceleration of gravity.

Field measurements partly reported by Shepard (1950) have indicated only partial agreement with current velocities predicted from the equation. The discrepancies appear to be due to:

1. Rip currents which normally increase the flow in the dominant direction on the up current side of the rip zone and decrease or reverse the current on the other side (Fig. 3).

2. Cell-like circulation of the nearshore system, which exists even under conditions of normal wave approach (breaker crests essentially parallel to the beach). According to the formula there should be no current under conditions of normal approach. However, with large breakers longshore currents of velocity of one or more knots have been observed for limited distances despite this normal approach.

3. The fluctuating nature of longshore currents which requires measurements over a long interval of time in order to obtain an average that is suitable for comparison with the predicted value.

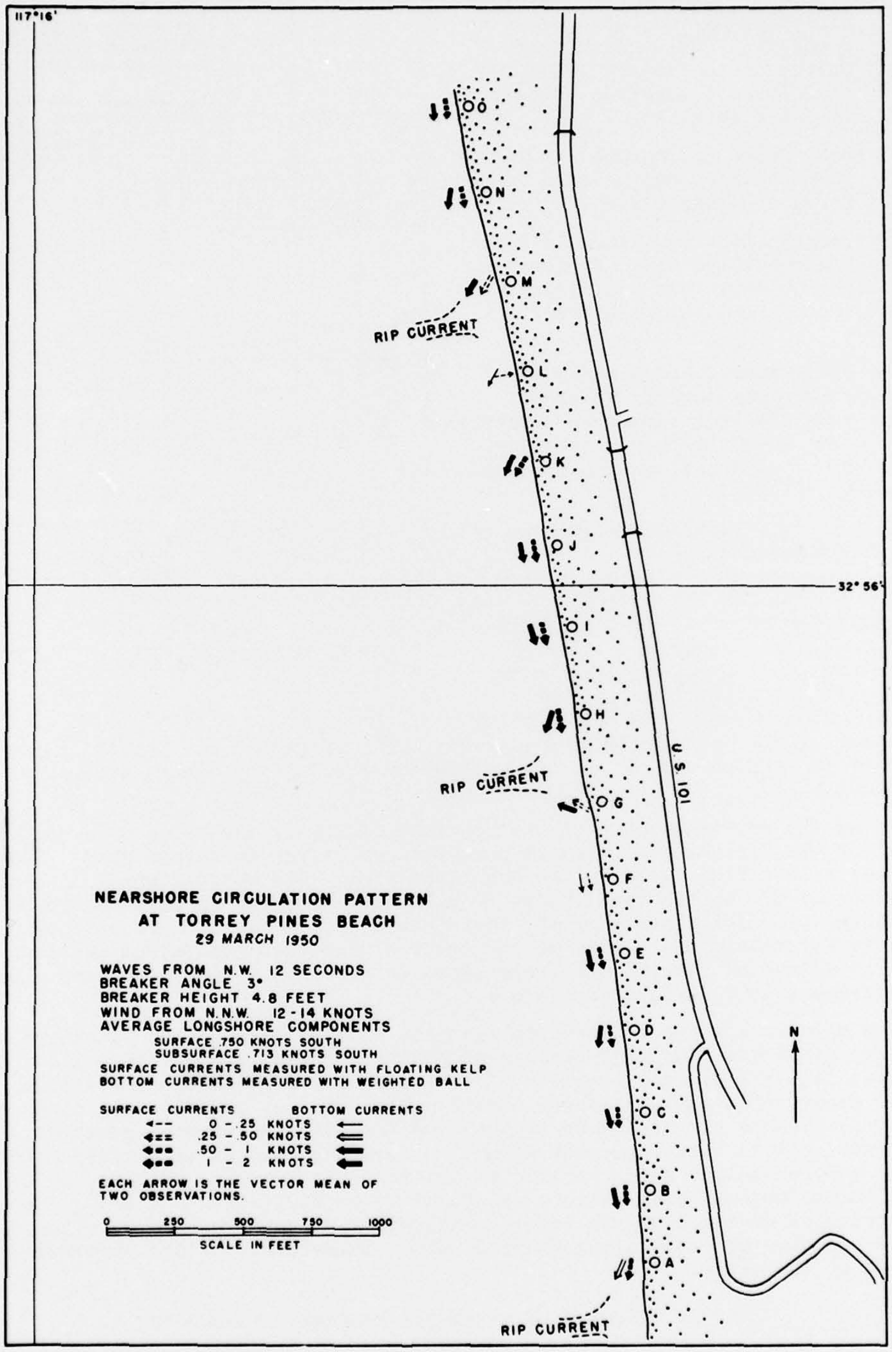

Fig. 3
Showing the influence of circulation pattern and rip currents on the direction and magnitude of longshore currents on a straight beach. Note that in the lee of rip current zones the longshore current is much reduced (station L) and sometimes reversed in direction (station G).

4. The fact that beach friction coefficient (k) was assumed to be a constant for a given beach. Further measurements indicated that it is a function of current velocity (Fig. 4).

5. Many beach approaches are terraced, making application of the formula impossible.

The nearshore circulation is frequently the result of waves approaching the coast from more than one direction, making current predictions extremely difficult.

Despite these discrepancies the longshore currents outside straight beaches with parallel submarine contours appear to be essentially the result of the factors considered by Putnam, Munk and Traylor (1949).

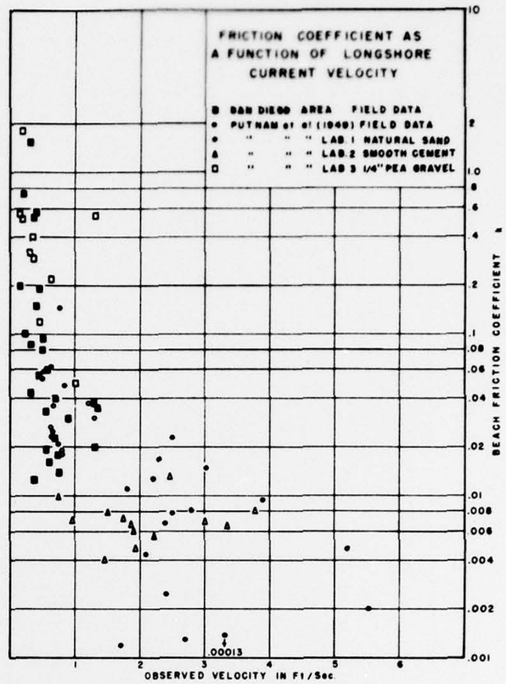

Fig. 4

The average longshore component of currents observed along two relatively straight beaches with parallel bottom contours in the San Diego area were compared with the currents predicted from equation 1. Preliminary plotting of the observed versus the computed velocity showed a rather large scatter, the amount of disagreement apparently being a function of the velocity of the current. This suggested the possibility that the friction coefficient, k, is not a constant for a given beach, but varies with the velocity.

Using the observed value of the longshore current, the value of k was computed for all of the field and laboratory observations listed in Putnam et al (1949) and for those recently obtained in the San Diego area. The coefficient k is plotted as a function of the observed velocity in Fig. 4. Inspection of this figure strengthens the contention that the coefficient k is a function of velocity, particularly for values of current of the order of two feet per second and less. Predicted values of longshore current based on k values from Fig. 4 have shown good agreement with field observations.

The regular spacing between rip channels cutting through the longshore bars along the straight, fine-sand beaches of northern Oregon and southern Washington indicates that the general features of the nearshore circulation pattern described in this report also apply to these northern beaches. At low tide the distance between rip channels can easily be ascertained from car speedometer readings. Observations of this type were made along the straight beaches of Clatsop Spit, Oregon, and Leadbetter Spit, Washington, on the 17th and 18th of June, 1950. The mean distance between rip channels was found to be 0.25 statute miles. The standard deviation of the distance between channels was found to be 0.09 miles for a ten mile section of beach along Clatsop Spit. These observations were made during a period of low waves.

BEACHES BORDERED BY IRREGULAR SUBMARINE TOPOGRAPHY

As yet there has been no quantitative approach to the prediction of currents or circulation along beaches bordered by irregular submarine topography. The situation differs from that existing along straight beaches with parallel contours in that the direction of longshore currents is dependent not only on the angle of wave approach but on the localized piling up of water on the beach at points of wave convergence. This local rise of sea level, the degree of which is still un-

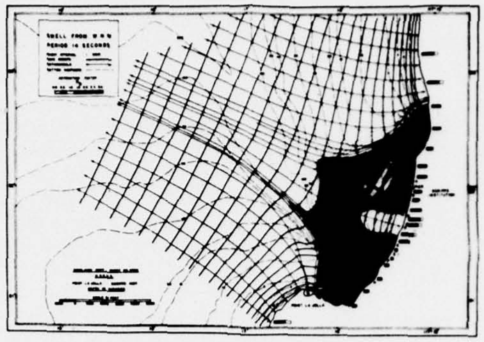

Fig. 5. Wave refraction diagram showing areas of wave convergence and divergence near La Jolla. The relative wave height is given by the length of the bar at various points along the beach. The letters A through H locate the same beach stations shown in Figs. 6 and 7. (From Munk and Traylor, 1947.)

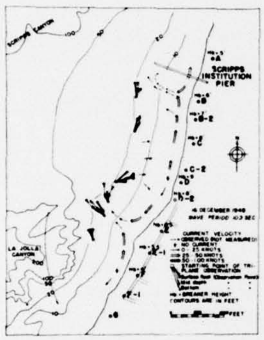

Fig. 6. The cell-like features of the nearshore circulation at Scripps Beach, La Jolla. The point of wave convergence is at station D, as shown by breaker height notation. (From Shepard and Inman, 1950.)

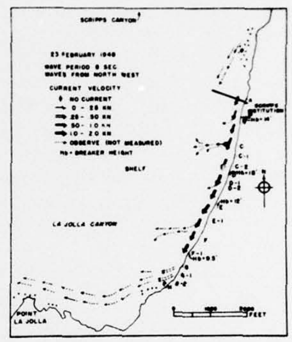

Fig. 7. For short period waves the wave convergence is not as pronounced, and the direction of longshore current is controlled by the direction of wave approach. (From Shepard and Inman, 1950.)

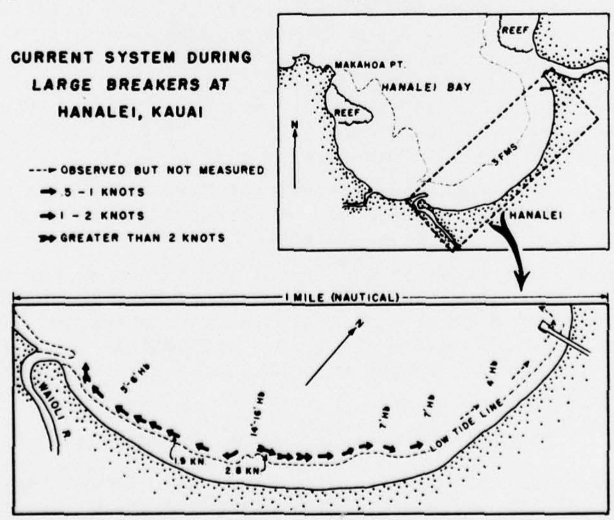

Fig. 8

known, results in a gradient along the beach and accompanying flow in both directions away from the convergence. These currents may be opposed in direction to the angle of wave approach.

Submarine canyons. Near those places where submarine canyon heads approach closely to the coast there are striking examples of wave convergence. At the canyon head the wave orthogonals diverge, decreasing the wave height, whereas they converge on either side, increasing the wave height (Fig. 5). In the La Jolla area it is not uncommon for the breaker height to be 10 times as high north of the two canyon heads as it is inside the heads. Current measurements outside the breakers at the convergence north of La Jolla Canyon indicate a movement towards the beach from the top to the bottom (Fig. 6). Inside the breakers the longshore currents flow away from the convergence in either direction. Rip currents commonly develop at points between the convergence and the divergence zone, where the waves are intermediate in height.

The current systems have been studied in two areas where canyon heads closely approach the coast: at La Jolla (Shepard and Inman, 1950) and at Mugu (Inman, 1950). In both areas the circulation pattern was found to be primarily dependent on the wave period. The longer period waves resulted in a sufficient degree of convergence so that the longshore currents flowed away from the zone of convergence. In this case the circulation cell is well developed and essentially fixed in position (Fig. 6) except as shifted slightly by changes in direction of wave approach. For shorter period waves the convergence is not as pronounced and the direction of wave approach becomes the controlling factor in determining the direction of longshore currents (Fig. 7). In this case the circulation cells are less stable and the position of the rips along the beach is variable. At La Jolla a strong blow accompanied by short period waves approaching diagonal to the coast produces constant current directions with the most pronounced rip at the bend in the coast in the down current direction (Fig. 7).

Crescentic Bay. On the north coast of Kauai in the Hawaiian Islands, Hanalei Bay forms a large crescentic bight into the main trend of the coast. During periods of high waves a large variation in wave heights was observed in a short distance along this bay (Fig. 8). In about a quarter of a mile breaker heights were observed to decrease from as much as 18 feet to 5 feet in one direction and at about half that rate in the other direction. This contrast is only partially explained by the small reefs which fringe both sides of the entrance. The highest breakers were comparable to those on the open coast so that they do not represent a convergence except relative to the adjacent portions of the bay. The longshore currents respond to this relative convergence in the same way as observed in areas adjacent to canyon heads. Currents as high as three knots were measured. At the point of greatest breaker height there is a low ridge extending seaward and the wave crests are bent around this ridge so that they come in directly against the strong outflowing currents. The flow is so strong as to produce a pronounced trough along the shore. In places these troughs are bordered by escarpments in the sand. As can be seen in Fig. 8, the flow away from the zone of high waves extends along the shore as much as three-quarters of a mile.

It is felt that these two cases including submarine canyons and crescentic bay by no means exhaust the possibilities of developing a local convergence with resulting divergent flow of longshore currents.

Small crescentic bays often show currents flowing in at one side and out on the other. During a 60 mile an hour gale at Nahant, Mass., currents were observed flowing in on one side of a small bay with velocities averaging about 4 or 5 knots. The outflow on the other side was much slower, indicating that there was a subsurface return flow. The surface inflow was continuous although considerably retarded during wave troughs.

CIRCULATION IN RELATION TO OBSTRUCTIONS

Points, breakwaters, and piers all influence the circulation pattern and alter the direction of the currents flowing along the shore. In general these obstructions determine the position of one side of the circulation cell. In places where relatively straight beaches are terminated on the down current side by

points or other obstructions, a pronounced rip extends seaward. During periods of large waves having strong diagonal approach these rips can be traced seaward for one or more miles.

At the north jetty of the Mission Bay Breakwater a seaward flow was frequently observed in the current lee of the jetty. This same seaward flow north of the jetty exists under most other observed directions of wave approach (Fig. 9).

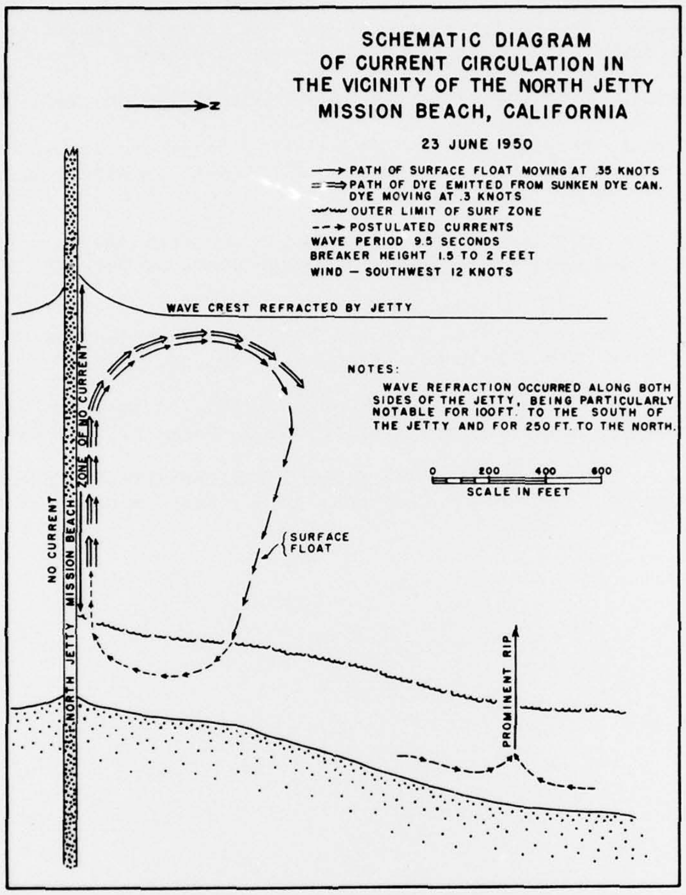

Fig. 9

Where prominent points of land interrupt the predominant longshore current flow, currents opposite in direction to that of the coast in general are likely to develop in the current lee of the point. Examples of this reverse flow have been observed in the lee of Dana Point (See Fig. 1 for location). Indirect evidence of currents flowing in this reversed direction are found where spits extend north in the current lee of obstructions such as at Morro Rock along the central California coast.

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